THE GLACIATION OF THE UINTA MOUNTAINS[1]

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OUTLINE

LOCATION AND GENERAL PHYSICAL FEATURES OF THE RANGE

The Uinta mountains are located in the northeastern portion of Utah. They consist of a single range of peaks extending in a general east-west direction. If the axis of the range were continued westward it would cross the Wasatch range nearly at right angles and enter the Bonneville basin a few miles south of Salt Lake City. Most of the range is included in the Coalville, Hayden Peak, Gilbert Peak, and Marsh Peak quadrangles of the Topographic Atlas published by the U. S. Geological Survey.

These mountains rise somewhat gradually above the plateau countries to the north and south. They reach their maximum elevation in the central portion of the range where the highest peaks are from 13,400 to 13,525 feet above the sea. The maximum elevation of the mountains above the surrounding country is about 7,000 feet. From the high central portion of the range the crest-line descends gently both to the east and to the west.

The width of the range is greatest in the central portion, where it measures, in a north-south line, fully 35 miles. To the east and west of the central portion the decrease in width is very notable. To the

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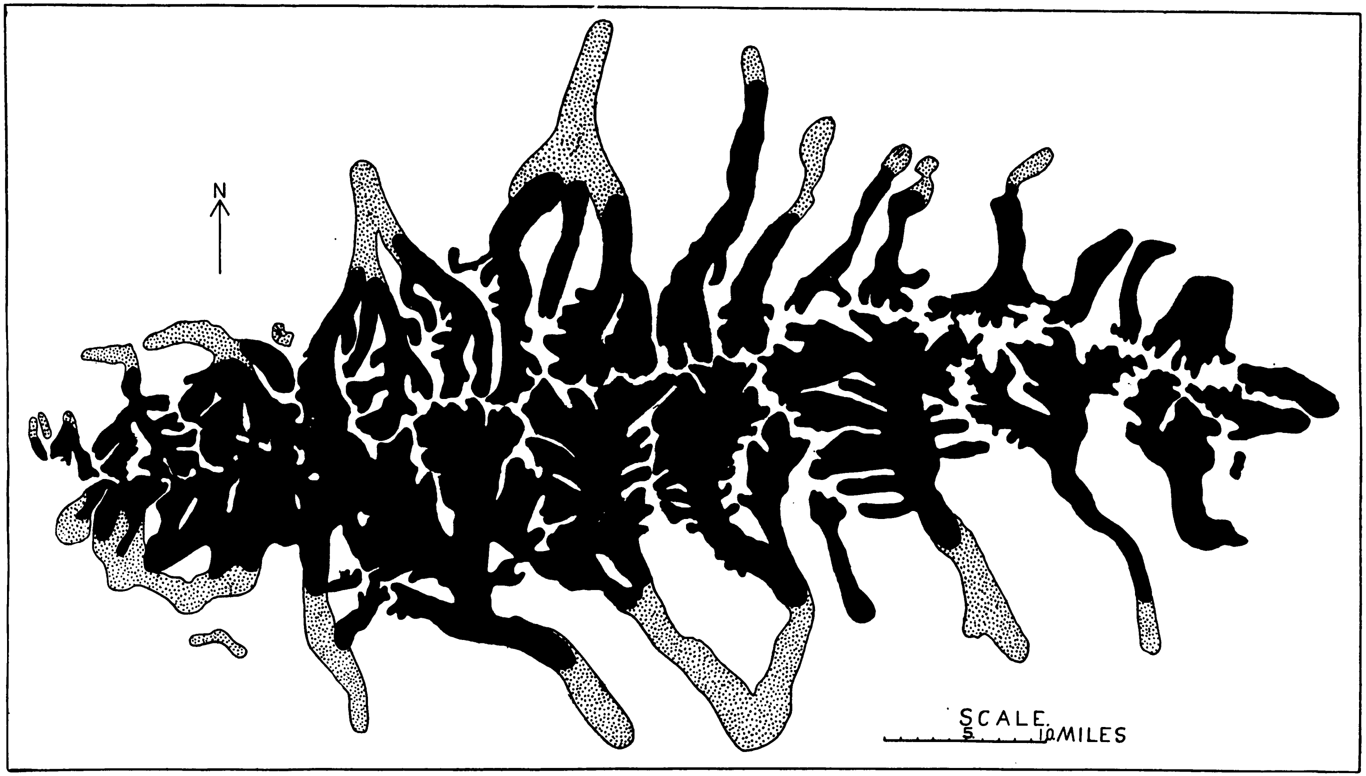

FIG. 1.—A map showing the extent and distribution of Pleistocene glaciers among the Uinta Mountains. Black represents areas covered by later epoch glaciers. Dotted portions represent additional areas covered by earlier epoch glaciers.

west the narrowing is symmetrical, and the terminus of the range is lobate in form, being sharply defined at the north and south by the valleys of the Weber and Provo rivers respectively. To the east the narrowing is not so pronounced or symmetrical, and, associated with the general flattening-out of the range in that direction, helps to account for the less conspicuous terminus at the east.

All the great canyons of the Uintas head near the crest of the range and descend approximately north or south. Since the axis of the range is nearer the north than the south margin, the north slope canyons are shorter than those on the south slope. All of the larger canyons have the characteristic U-shaped form due to glaciation. They have been well cleaned out by the ice in their upper portions, but in the middle and lower portions they contain heavy morainic deposits.

On the north slope, at the heads of the canyons, the basins vary from one to twelve square miles in area, while on the south slope they commonly include from twenty to thirty square miles (see Fig. 1). This difference, which had a very notable influence on the size of the glaciers, is consistent with the general structure of the range and will be discussed later.

THE EXTENT OF GLACIATION

At the period of maximum extension the ice covered by far the greater portion of the mountains west of Longitude 109 degrees, 40 minutes, and in a few cases extended beyond the mountains into the lower country to the north and south. The maximum extension of glaciation in an east-west direction was 82 miles, and in a north-south direction 42 miles. The total area covered by ice was something over 1,000 square miles. The portions of the range that rose above the ice near the crest-line were lofty peaks and narrow, rugged divides (see Figs. 2 and 3). Near the western end of the range in the region about Hayden Peak, Bald Mountain, Reids Peak, and Mount Watson, there was a great ice cap (see Fig. 1). Above this ice cap a few lofty summits (Fig. 2) rose as nunataks and helped to direct the movement of the ice into the canyons leading from this great center of accumulation. Six of the larger glaciers in the western portion of the range originated in this ice cap.

On the flanks of the range the areas not covered by ice were between the great canyons. These areas became broader and broader to the north and south, beginning as narrow ridges near the crest-line (Fig. 3), and broadening to plateau-like areas near the foothills. The portion of the range that rose above the snow-fields associated with the glacier must have been much less than that which rose above the ice. There is no way of determining how high the snow rested, but it is fair to assume that aside from a few lofty peaks

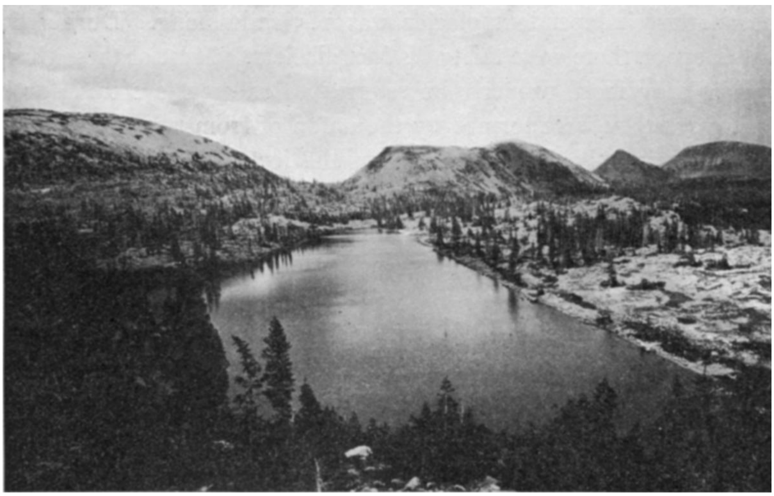

FIG. 2.—A portion of the Provo Basin. The passes have been glaciated but the peaks rose above the ice. The lake in the foreground is in a rock basin that was gouged out by the ice.

and narrow ridges the range appeared as a long white arch, rising about 7,000 feet above the country to the north and south, and suggestive, in form at least, of a partial reconstruction of the great Uinta anticline.

Most of the catchment areas in which glaciers were formed are 10,000 feet or more above the sea. A few favorably located basins between 9,000 and 10,000 feet furnished ice. The lower glacier basins are all near the western end of the range, where the snowfall was presumably greatest. Near the eastern margin of glaciation there are many basins above 9,000 feet in elevation that did not

contain ice. Three of the basins below 10,000 feet contained ice during the earlier epoch, but not during the later, indicating that, in general, a greater elevation was necessary for the formation of glaciers during the later than during the earlier epoch.

The glaciers extended southward and northward from the main crest-line, reaching their greatest lengths in the central portion of the area and decreasing in length both to the east and west, thus exhibiting a dimensional symmetry appropriate to the form of the range (see Fig. 1). The longest glacier was 27.5 miles in length; the shortest independent glacier was 1.5 miles long. During the earlier epoch there were thirty distinct glaciers. Most of these thirty glaciers may more properly be referred to as great systems, for in most cases they were formed by the union of from two to eight glaciers. During the later epoch, when the ice was not so extensive, fewer glaciers united, especially on the north slope, and therefore there was a larger number of distinct termini to the ice. The total number of independent glaciers during the later epoch was thirty-nine.

If the great systems of the earlier glaciers be subdivided and the tributary glaciers be counted as independent glaciers, there were:

8	glaciers	20 miles or over in length
3	"	15 to 20 miles in length
9	"	10 to 15 " " "
21	"	5 to 10 " " "
63	"	1 to 5 " " "

or a total of 104 glaciers over 1 mile in length.

COMPARISON OF THE GLACIATION OF THE NORTH AND SOUTH SLOPES

The lengths of the glaciers on the north and south slopes were, on the average, during the earlier epoch, about ten and sixteen miles, respectively. During the later epoch the lengths of the glaciers on the north and south slopes were about eight and ten miles, respectively. There were but two glaciers on the north slope that reached twenty miles in length, while on the south slope there were six that exceeded that length. The lower limits of glaciation on the two slopes are shown in the following table:

	Maximum Lower Limit during Earlier Epoch	Maximum Lower Limit during Later Epoch	Average Lower Limit during Earlier Epoch	Average Lower Limit during Later Epoch
North Slope...............	7,200	7,500	8,165	8,500
South Slope...............	6,600	7,250	7,661	8,112

The explanation of these striking differences seems to rest fundamentally on the general structural conditions in the range. The fact that the crest-line is nearer the north than the south margin of the mountains is of extreme importance. As a consequence, the north slope canyons are shorter than those on the south slope. They descend more quickly to elevations where ablation overcame the onward movement of the ice. Furthermore, the basins on the north slope are in a zone of inclined strata, while the south slope basins are located in the midst of essentially horizontal beds. These structural conditions account for the greater development of the catchment areas on the south slope than on the north slope. The widening of the basins, to be discussed more fully later, progressed more rapidly in the region of horizontal strata than where the beds are inclined. The larger catchment areas and the longer canyons are sufficient to explain the more extensive glaciation on the south slope. These factors seem to have outweighed in importance the greater protection from the rays of the sun on the north slope and the more favorable location for the lodgment of wind-blown snows on the north. The angle of the sun's rays must have caused more rapid melting on the south side, and the prevailing southwest wind must have carried much snow from the southern catchment areas and contributed to the northern fields, and yet, with the immense basins and long routes to low altitudes, the south slope glaciers far exceeded in magnitude those on the north slope.

GLACIAL EPOCHS

The chief facts about the extent of the ice during the different glacial epochs have been given. On the average, the earlier glaciers advanced from five to six miles farther down the canyons than did the later. In three basins there appears to have been ice during the earlier epoch and not during the later. A comparison of the lower

limits of glaciation during the two epochs is shown in the table already given.

The recognition of distinct glacial epochs among the mountains has associated with it some peculiar difficulties. When ice descended

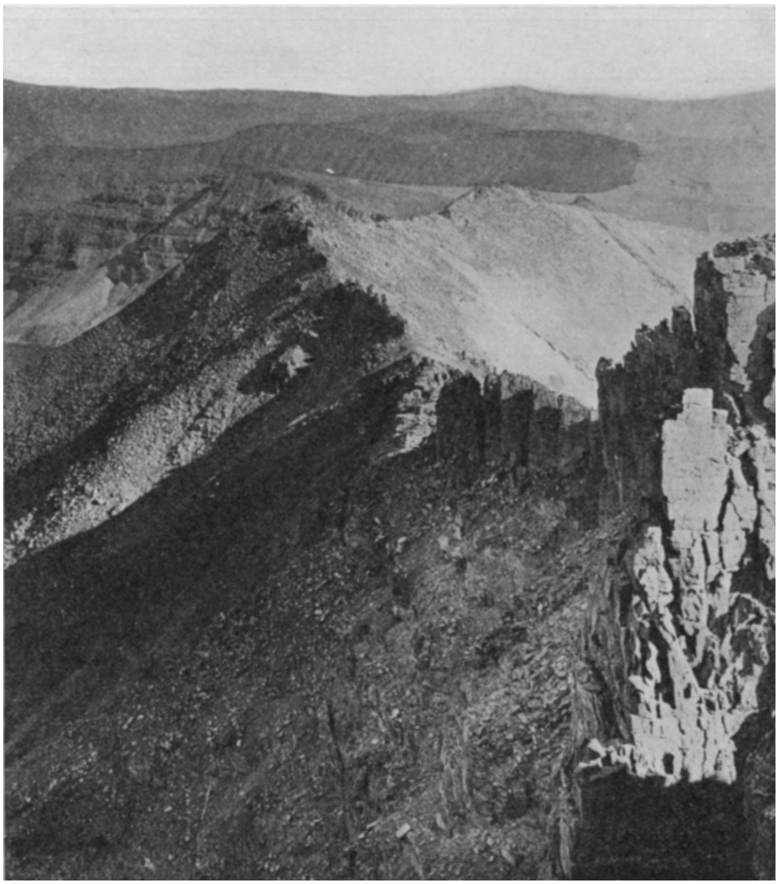

FIG. 3.—One of the sharp divides in the basin region.

a canyon it was quite apt to obliterate all traces of any earlier ice advances through the same course. This was particularly true if the later ice advanced as far as any earlier ice. The chances of finding buried drift in these restricted courses of the ice are therefore much poorer than in the open country invaded by the continental

ice sheet. The mere fact that the area in which the data must be found, to prove distinct epochs for a given canyon, is so small, enhances the difficulties in the problem, and greatly reduces the chance of a demonstration. Where the later ice did not advance as far as the earlier, the case is more hopeful. In fact, in every case where distinct epochs have been determined in the western mountains, so far as the writer is aware, the earlier ice was more extensive than the later. In such cases the outer moraines have been subject to the processes of weathering and erosion for a longer period than the later or inner moraines. There may also be, associated with the two distinct systems of moraines, distinct outwash-deposits. These outwash-deposits must have a genetic relationship with the terminal moraines of the two epochs, and the older alluvium or valley-train may be expected to have suffered greater erosion than the younger. The composition of the glacial drift in a mountain canyon will be essentially the same each time that ice descends to a given point. But if the drift contains some easily weathered material, such as the coarsely crystalline rocks, the difference in the amount of weathering or disintegratio nof the bowlders may become a strong argument. Among the Wasatch Mountains the older and the younger moraines may be easily distinguished by the difference in the amount of weathering. Among the Uintas this line of evidence is almost entirely wanting. The drift among the Uintas is composed largely of quartzite, in fact so largely that in most cases it is difficult to find a specimen of any other kind of rock in the drift. The drift of certain canyons is composed entirely of quartzite. Furthermore, the quartzite of the Uintas is so hard that the bowlders in preglacial conglomerates, derived largely from this formation, appear nearly as fresh as those in the youngest glacial deposits. The only difference that can be made out in the amount of weathering of the preglacial quartzite conglomerate and the quartzite moraines is that in the former there are more and larger bowlders that have been fractured, presumably by changes in temperature and by frost.

The determination of two epochs of glaciation among the Uintas rests chiefly upon these points:

1) There are two distinct systems of moraines in each of the main canyons.

2) The outer moraines are much more deeply eroded than the inner. Usually the outer terminal moraine has been entirely removed by erosion.

3) In some cases, where an older lateral moraine rests on a canyon slope above a younger moraine, the difference in the amount of erosion which each has suffered is very marked. Often there are valleys crossing the upper moraine which fail to cross the lower, and therefore appear as blocked valleys in drift above the lower moraines,

FIG. 4.—A glacial cirque in the western portion of the Uinta Mountains. The vertical walls and comparatively even floor are common characteristics of the catchment areas in the range.

just as blocked valleys in rock appear in the rock above the upper moraines.

4) Corresponding to the greater erosion in the outer moraines, there has been greater deposition. In many of the canyons, immense alluvial fans have been developed by side-streams that enter the main valleys at points below the terminal moraines of the later epoch and above the terminal moraine of the earlier epoch.

5) Depressions in the older drift have commonly been filled with alluvium. In this way, possible lakes or marshes have been obliterated. In the older moraines there are but few lakes and marshes while in the younger moraines lakes and marshes are common.

6) In three canyons there appears to have been ice only at a much earlier period than that of the later epoch.

7) In some cases two distinct valley trains have been determined, one being associated with the outer and the other with the inner moraines.

The alternative interpretation of the glacial deposits in the range is that the so-called younger moraines are recessional moraines deposited by the same ice that built up the outer older ridges. The marked differences in the age of these two series of moraines make this interpretation unsatisfactory. The time necessary for the removal of the outer terminal moraine, and the excavation of broad valleys in which the younger valley trains were deposited, must have been many times, perhaps ten, or twenty times, as long as the period that has elapsed since the final melting of the ice.

THE INFLUENCE OF TOPOGRAPHY UPON THE ICE

In an earlier paragraph it has been pointed out that the formation of the Uinta glaciers has been controlled by the size and elevation of the catchment areas. The case is equally clear that the movements of the ice were, in a large measure, dependent upon the topography of the range. At some places the divides were covered by ice, and yet in such places the underlying rock divides controlled the direction of ice movement, causing movement in opposite directions in a continuous ice mass. In the catchment areas the movement was in general pointed toward the canyon. From certain catchment areas the ice was forced to pass around isolated peaks and ridges that rose above the ice as nunataks; in some cases, to divide and move down different canyons on the same slope. The canyon ice was frequently forced by some projecting rock spur to swing to one side or the other. At constricted portions in the canyons the ice responded somewhat as rivers do and worked its way through the narrows, to deploy as soon as the walls of the canyon permitted. At several points the canyon ice was required to turn at right angles in order that it might move down valley.

THE INFLUENCE OF ICE ON THE TOPOGRAPHY

While the ice responded to topography, and in a large measure was controlled by the physical features of the range, yet at the same

time it was modifying the forms encountered, changing the shape of the great canyons, and building new forms.

Before the first Pleistocene snows fell on the Uinta Mountains, the heads of the great canyons may be fairly assumed to have been narrow V-shaped notches, reaching in most cases nearly to the crest-line of the range. The first ice was formed in these narrow canyon heads, and the earliest movement must have been distinctly down canyon. As the ice at the heads of the canyons increased in thickness, there came to be a notable movement down the sides of the gorge, concentrating the ice in the canyon and causing further movement down stream. With the movement of the ice on the side slopes, these miniature catchment basins were both widened and lengthened. About the margin of the ice fields weathering and ice plucking was in progress. Such work has been pointed out by Johnson[1] to be going on today at the base of the Bergschrund. In this way the catchment areas were increased in size and changed into cirque-like forms (see Fig. 4). Such work has been described by Penck[2] as follows:

> Glaciers not only exercise a sapping action along their sides, but also at their very heads, if they are here overlooked by rock cliffs. There is always a marginal crevasse, called in German, Randspalte or Bergschrund, which separates the moving ice from the rocks which overlook it. The material loosened here by weathering falls down from the rock walls into this crevasse and arrives at the bottom of the névé, where it is pushed forward by the mass grinding the bottom of the glacier. By this, not only the formation of screes around the glacier is hindered, but also the surrounding cliffs are constantly attacked, for the erosive action begins just at their foot and saps them. Glaciers therefore, which are formed on slopes in broadly open valley basins, surround themselves finally by cliffs, which are pushed backward much as are the cliffs around the gathering basin of a torrent.

Just south of the main crest-line, weathering and the plucking work of the ice went on under the most favorable conditions. There the strata are essentially horizontal and sufficiently variable in hardness to favor rapid disintegration. The giving-way of the softer beds left the overhanging harder strata exposed. Cliff and talus slopes developed, and the ice, working sideward and headward, or in general

[1] *Journal of Geology,* Vol. XII, p. 573.

[2] *Journal of Geology,* Vol. XIII (1905), p. 15.

outward, around the margin of the ice field, would work these steps or benches farther and farther back. Sometimes a very resistant layer of quartzite served for several square miles as a base to which the quarrying work of the ice went on. Then another resistant layer, 10, 20, or even 200 to 300 feet higher, would serve as the floor of the quarry. The work therefore went on in something of the fashion in which men widen and deepen quarries in similar formations. Many abandoned benches remain today about the margins of the great catchment areas.

Corresponding to the widening of the basins, there was a narrowing of the divides between the heads of the canyons and of the main crest of the range. Some of the divides (see Fig. 3) were so reduced that it is dangerous to try to walk along them. Others were surmounted and greatly reduced by the ice. The main crest-line was sharpened, and the peaks were given greater prominence.

In the canyons the great change was the development of the broad U-shaped troughs. The preglacial forms were largely obliterated. The canyons were widened and deepened. In this process many tributaries were left as hanging valleys with their lower ends several hundred feet above the main stream. Preglacial erosion lines, and asperities common to the slopes of unglaciated canyons, were commonly rubbed off as far up as the ice rested.

In the bottom of the gorges, on the canyon walls, and in the basins, the glaciers built up new topographic forms. The terminal moraines have an average depth of about 400 feet. In one instance, however, it is clear that there is at least 1,000 feet of morainic material at the mouth of the canyon. These moraines are often ridgelike in form but where the glaciers pushed out on the lowlands bordering the mountain range, they have a hummocky topography similar to the terminal moraines left by the continental ice sheet of the interior region. At intervals, up stream from the terminal moraine it is customary to find other morainic ridges or belts crossing the valley in the manner of recessional moraines. Above these recessional moraines lakes are sometimes located, but more commonly swamps, which are being drained as the main streams lower their courses through the morainic dams. The lateral moraines are lodged as ridgelike forms on the valley slopes. The crest-lines of these lateral ridges increase in

elevation above the stream bed for several miles up the canyon from the terminal moraines, until, near the basin region, the canyon walls become too steep to permit the lodgment of loose débris. The elevation of the lateral moraines indicates that the ice in many of the canyons was but 600 or 700 feet thick, but where the larger glaciers existed the ice was from 1,500 to 2,000 feet thick, and in one case 2,500 feet thick. The extensive terraces extending down stream from the terminal moraines are remnants of valley trains deposited by the waters associated with the glaciers.

POLISHED AND STRIATED SURFACES

The polished and striated surfaces of bed rock are restricted almost exclusively to the basin regions. In the areas where the drift is scarce, striae, grooves, polishings, and *roches moutonnées* are common. Square miles of bed rock are exposed in the higher portions of the range, where the signs of ice action are beautifully shown. In many of the passes in the main crest-line, glaciated surfaces appear. Striae have been found as high on some of the peaks as any other signs of ice action, and about the marginal portions of the basin regions ice action is often recorded both in glaciated surfaces and ice-gouged basins in the hard quartzite rock. A few striated rock surfaces have been found deep in the canyons and on benches or shoulders on canyon walls.

INFLUENCE OF GLACIATION ON DRAINAGE

The hundreds of glacial lakes and marshes indicate, especially in the basin region of the range, how generally the drainage has been modified by the ice. Scarcely a basin exists where waters are not yet ponded by the morainic deposits or retained in rock basins gouged out by the ice. In a few cases tributary streams in unglaciated valleys have been ponded by lateral moraines of a main canyon. Terminal and recessional moraines have in some canyons blocked the courses of the main streams and caused the formation of chains of lakes. At the close of the glacial period such chains were much more common than they are today, but in their places are chains of meadows, separated from each other, as the former lakes were, by morainic ridges. There are now more than 550 glacial lakes among

the mountains. In the catchment basin of Provo Canyon there are at least forty-three lakes, and from the summit of Bald Mountain overlooking the area formerly covered by the ice cap seventy lakes may be seen. In a few cases streams are today partially ponded by morainic dams. In these cases the drift is not sufficiently compact to hold the waters until they rise and overflow, but, seeping through the loose deposits, the waters issue a short distance down the canyon as large springs. The glacial lakes vary in their longer diameters from a few rods to one mile and a half. Most of them, however, are less than half a square mile in extent.

The hanging valleys may also be mentioned in this connection, for they are instances of marked changes in drainage. In this way scores of tributary streams have been thrown out of adjustment with their mains. Falls and rapids have been caused which centuries of work may not remove from the stream courses.

POSTGLACIAL WORK

Since the ice last left the Uinta Mountains, the work of weathering and erosion has been, with the exception of certain inner gorges on the south slope, trivial and insignificant. The moraine material of the later epoch is but little disintegrated, and most of the streams are yet engaged in cleaning away the glacial débris from their courses. Near the summits changes in temperature, frost, gravity, and moving névé, have so combined as to produce extensive talus accumulations about the margins of the basins. The inner rock gorges in the main south slope canyons are the most striking postglacial features in the range. On the average they are fifty to eighty feet deep and from five to six miles long. They are limited to the upper portions of the canyons, and do not appear to be due to a general rejuvenation of the streams. They are in those portions of the canyons where the deepening by the ice was greatest, and therefore where the stream bed would be expected to be relatively low, and yet these inner rock gorges are distinctly below the level of ice wear and are not glaciated. The favorite hypothesis for the explanation of these gorges has been a slight postglacial uplift along an east-west line about ten miles south of the axis of the range.

GLACIATION AND IRRIGATION

The present streams from the Uinta Mountains, if under control, would furnish enough water to irrigate hundreds of square miles in the lower country. If the glacial lakes were connected directly with the streams and used as reservoirs, the irrigating capacity of the streams would be immensely increased. Usually a relatively inexpensive dam would control the waters of these natural reservoirs. In most cases the lake waters could be easily increased a few feet in depth, and often spread over many additional acres of land. In a few cases simple efforts have been made to control the waters in such lakes. China Lake, in the east fork of Smith's Fork, now serves as a reservoir. At the south end of Lake Washington in the Provo Basin a dam was built which, if effective, would have raised the waters in the lake a few feet and reserved a large supply of water for the latter part of the growing season. The dam is now broken, and the outlet of the lake is being gradually lowered by the outflowing waters. In many cases outlets of former glacial lakes could be closed and new reservoirs made. Often the younger terminal moraines in the canyons have but narrow notches cut through them. If these post-glacial notches were closed, there would be extensive reservoirs in the lower portions of the canyons.

Most of the irrigable land south of the mountains is at present owned by the Ute Indians. The Indians carry on some agricultural work, but only near the streams, where the land is very easily watered. The country north of the range is inhabited by ranchmen, who find it more and more necessary each year to raise fodder for their stock. The land is being rapidly taken up and fenced off for private ranges. In this country irrigation is practiced somewhat extensively, and yet little or nothing has been done to control the waters in the basin region or to develop new reservoirs lower down in the canyons. Each year the streams are lowering the outlets of the lakes and both widening and deepening the cuts through the moraines in the canyons, and therefore the amount of work necessary to get control of the water supply in the range steadily increases.